September 9, 1953

Dr. T. H. Johnson, Director
Division of Research
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Dr. Johnson:

As you know, over the past several months we have been carrying forward
the development of alternating gradient synchrotrons and have been studying care-
fully their technical and economic feasibility with a view toward a possible
accelerator at Brookhaven. Our FY 1955 budget submission of April 3, 1953, made a
first tentative proposal for a 50 Bev machine, estimated to cost approximately
$30,000,000. Since we understand that funds for beginning such a project might be
made available this year, and since our technical information and ability to estimate
costs have advanced considerably during the last six months, we have in recent weeks
been working toward the crystallization of a more definite proposal. This letter
will outline our conclusions and propose a design and construction program to be
initiated as soon as possible.

In studying the situation, we have, as usual, attempted to balance the
probable scientific utility of any proposed accelerator against initial cost in
money and technical effort, the time required for its completion and the complexity
and cost of its operational use. Since the various considerations are detailed and
complicated and since the scientific considerations are in many ways intangible, I
shall attempt in this letter to discuss them only in broad outline.

Particles of energies far in excess of any conceivable in the laboratory
are, of course, available in cosmic rays and their utilization has been of inestimable
value in studying fundamental nuclear particles and the forces between them. These
particles are, however, so few in number and the situation is so complex that quanti-
tative experiments are often difficult or impossible but must rather be carried out
under the controlled laboratory conditions made possible by high energy accelerators.
That such machines are of great utility within their available energy ranges has
already been strikingly demonstrated by the existing synchro-cyclotrons and more
recently by the Cosmotron. For example, the latter has, during its relatively short
operational use, yielded much new data on meson yields, and on the energy dependence
of π meson and fast neutron cross sections and has even led to the observation of
certain hitherto unobserved heavy meson phenomena. That extension of the available
energy would yield many fruitful results seems unquestionable; indeed, it is already
possible to visualize many useful experiments requiring considerably higher energies.

Although many of these will be made possible by the 6 Bev soon to be available at the University of California Bevatron, still further extension seems highly desirable, for specific and predictable reasons as well as on the general grounds that past extensions of energy have always proved highly profitable.

Fortunately, the discovery of alternating gradient ("strong") focussing has so advanced accelerator art that appreciable extension of the available energy to meet the scientific need is now technically and economically feasible. In contrast to conventional synchrotrons in which the magnet weight, already quite large for the Bevatron, would quickly grow to unmanageable proportions because of its cubic dependence on energy, the strong focussing synchrotron requires a magnet of much smaller cross section which, within a wide range, is much less energy dependent. In contrast to the magnet and power supply of standard synchrotrons, which already account for one fourth of the total cost at the 3 Bev energy of the Cosmotron, those of strong focussing synchrotrons account for so large a fraction only above about 35 Bev. The difference is strikingly illustrated in Figure 1 which compares quantities of steel required for a conventional synchrotron, based on Cosmotron experience, with those which we estimate to be required in strong focussing synchrotrons.

The smaller aperture requirements also result in appreciable savings in size and cost of the vacuum chamber and hence in the accelerating electrodes and the r-f power required to drive them. On the other hand, the remainder of the r-f system is at least as complex in the strong focussing as in the conventional synchrotron. The small aperture requires correspondingly greater frequency accuracy at relativistic energies, and a strong impact results from the phase shift requirement at one point in the acceleration cycle. The quadratic dependence of "volts per turn" on maximum energy for a fixed acceleration period still obtains, so that the number of accurately phased accelerating stations becomes large at very high energies, and is, indeed, probably the most markedly energy dependent of all the technical (as distinguished from the economic) factors.

Our estimates of costs of strong focussing synchrotrons in the range from 15 to 100 Bev are plotted against energy in Figure 2. As seen, they extrapolate to a zero energy intercept of approximately $6,000,000, representing the costs of basic development and design, of components such as the injector which are not energy dependent in the range of interest, and of such relatively fixed necessities as utility lines, development and construction space, etc. As a function of center of mass energy, the overall cost rises slowly at first but with increasing rapidity at the higher energies as the magnet and the r-f system begin to dominate. A broad but definite minimum in cost per Bev exists at approximately 5 Bev (24 Bev, laboratory system). A similar, but less energy dependent curve could probably be plotted for the technical effort required; the intercept and slowly varying part would consist of design of the magnet, the vacuum system, the injector and the general control system (including means for accomplishing the phase shift); the strongly energy dependent part would represent the r-f system and the general difficulties associated with testing and integrating the parts of an increasingly large and complex system. Similar considerations no doubt apply to the effort and cost of operational use.

From the above, it seems evident that construction of too small a machine would be technically and economically wasteful, but that, on the other hand, the highest energies considered become, with present techniques, so expensive in effort, money and time as to be not justified in the light of predictable scientific needs. An intermediate energy seems, therefore, most appropriate.

The specific proposal which we have developed is for an accelerator very conservatively designed for an initial laboratory energy of 25 Bev but with the potentiality of ultimately achieving 35 Bev, probably in a second step. The machine would incorporate a magnet capable of containing 25 Bev particles with a magnet field of 10,000 gauss, at which value the field distorting effects of iron saturation are just beginning to be felt. Since, however, we feel certain that corrective measures permitting useful fields of, say 14,000 gauss are entirely feasible, the power supply would be designed for this higher value and appropriate correcting magnets and coils would be incorporated in the construction; the elaborate, though not necessarily expensive, external controls for these devices would, however, probably be omitted in the first step (just as was the powering of the pole face windings in the Cosmotron) in order to speed up initial availability of the machine and to profit by operational experience.

It may also be possible to use a simpler r-f system in the initial than in the final step. For a given acceleration time, the "volts per turn" would be only 5/7 as great, and the time might well be extended by, say 50% without exceeding the design power dissipation (the peak current being less), making an overall reduction in r-f requirements of approximately one half. This simplification is, however, somewhat more problematical than that of the previous paragraph since the phase transition difficulty may be increased by lowering the acceleration rate.

The principal parameters of the proposed machine are summarized in Table I.

TABLE I.

Orbital radius of curvature	260 feet
Overall diameter	625 feet
Maximum field – Step 1.	10,000 gauss
Energy – Step 1.	$\sim$ 25 Bev
Maximum field – Step 2.	14,000 gauss
Energy – Step 2.	$\sim$ 35 Bev
Injection energy (Linac)	50 Mev
Pulse repetition period	5 Sec.
Estimated intensity	$>$ 10^9 protons/pulse

The presently contemplated building layouts are indicated in the enclosed sketches which are self explanatory.

Table II lists our estimates of costs for the final machine. Those attributable to Step 2 represent only a small part of the toal since it adds principally to complexity of control functions rather than massive and costly major components.

TABLE II.

Costs in thousands of dollars.

	Materials and External Services	Internal Costs	Total
General Development & Design		2,000	2,000
Electron Analogue [1]	200	400	600
Magnet & Power Supply	4,400	300	4,700
Vacuum System	500	300	800
Injection System	1,200	500	1,700
Radiofrequency System	1,000	700	1,700
Controls	600	500	1,100
Special Equipment [2]	1,500	- -	1,500
Substation	200	- -	200
Cooling Tower	160	- -	160
Magnet Enclosure (20 ft. x 2,000 ft.)	1,200	- -	1,200
Experimental Area (30,000 sq. ft.)	1,350	- -	1,350
Linac Building (6,000 sq. ft.)	220	- -	220
Power Rooms (10,000 sq. ft.)	330	- -	330
Shops & Assembly Area (14,000 sq.ft.)	440	- -	440
Labs, Offices & Service Area (30,000 sq. ft.)	680	- -	680
Utility Lines, Roads, Etc.	900	- -	900
Steam Boiler [3]	400	- -	400
	15,280	4,700	19,980

[1] Described in my letter of August 21, 1953.

[2] Radiation shield, cranes, wireways, air conditioning of machine proper.

[3] To be incorporated in central steam plant. Coordinated with Master Plan.

More detailed breakdowns of costs will be incorporated in revised budget submissions which will be transmitted to Mr. Van Horn in the near future.

We estimate the time to completion of step one as five to six years from the present time. The second step (if not done simultaneously) would be delayed from one to two years.

Should authorization to proceed be granted in the immediate future it would be advantageous to have available for commitment in FY 1954 approximately $2,500,000 to meet the following immediate needs:

Electron analogue	$ 500,000
Building & utilities design	460,000
Utilities construction	820,000
Injector parts (trial section only)	200,000
Magnet foundation	300,000
Miscellaneous purchases & services	200,000
	$2,480,000

I trust that the foregoing is sufficiently explanatory for your present purposes. We shall, of course, continuously amplify it as information develops and as the need arises.
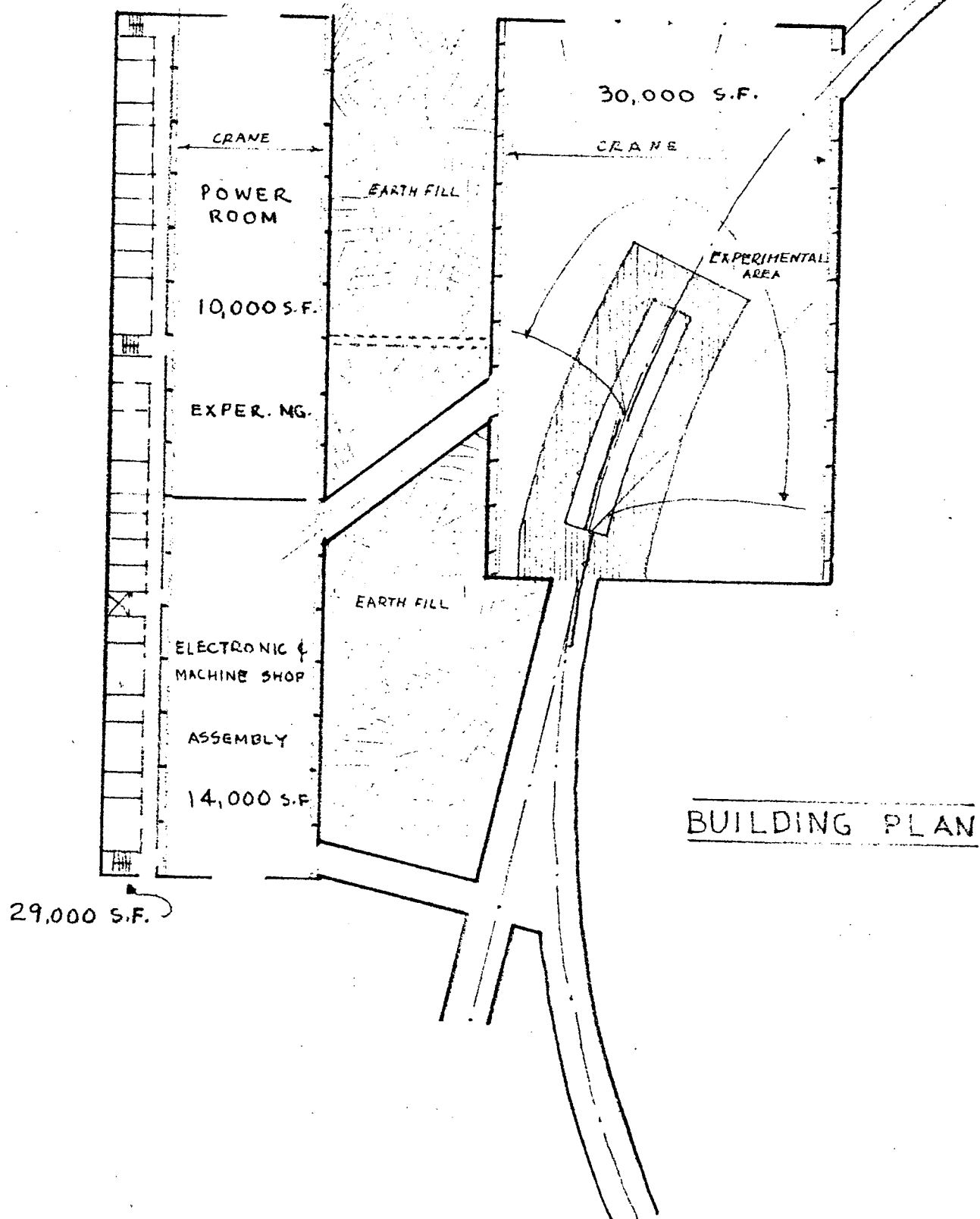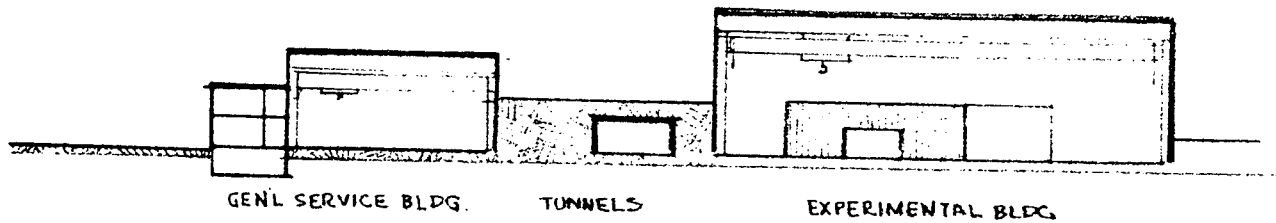
Sincerely yours,

/s/ Leland J. Haworth

Leland J. Haworth,
Director.

LJH/ak
Encs.

cc: E. L. Van Horn

GEN'L SERVICE BLDG.   TUNNELS   EXPERIMENTAL BLDG.

POWER ROOM

10,000 S.F.

EXPER. NG.

CRANE

EARTH FILL

30,000 S.F.

CRANE

EXPERIMENTAL AREA

ELECTRONIC & MACHINE SHOP

ASSEMBLY

14,000 S.F.

EARTH FILL

29,000 S.F.

BUILDING PLAN

TONS
WEIGHT

100,000

STANDARD
SYNCHROTRON

50,000

ACTUAL
COSMOTRON

ALTERNATING GRADIENT SYNCHROTRON

10   20   30   40   50 BEV

Fig. 1. Magnet weights as functions of energy. The standard synchrotron curve
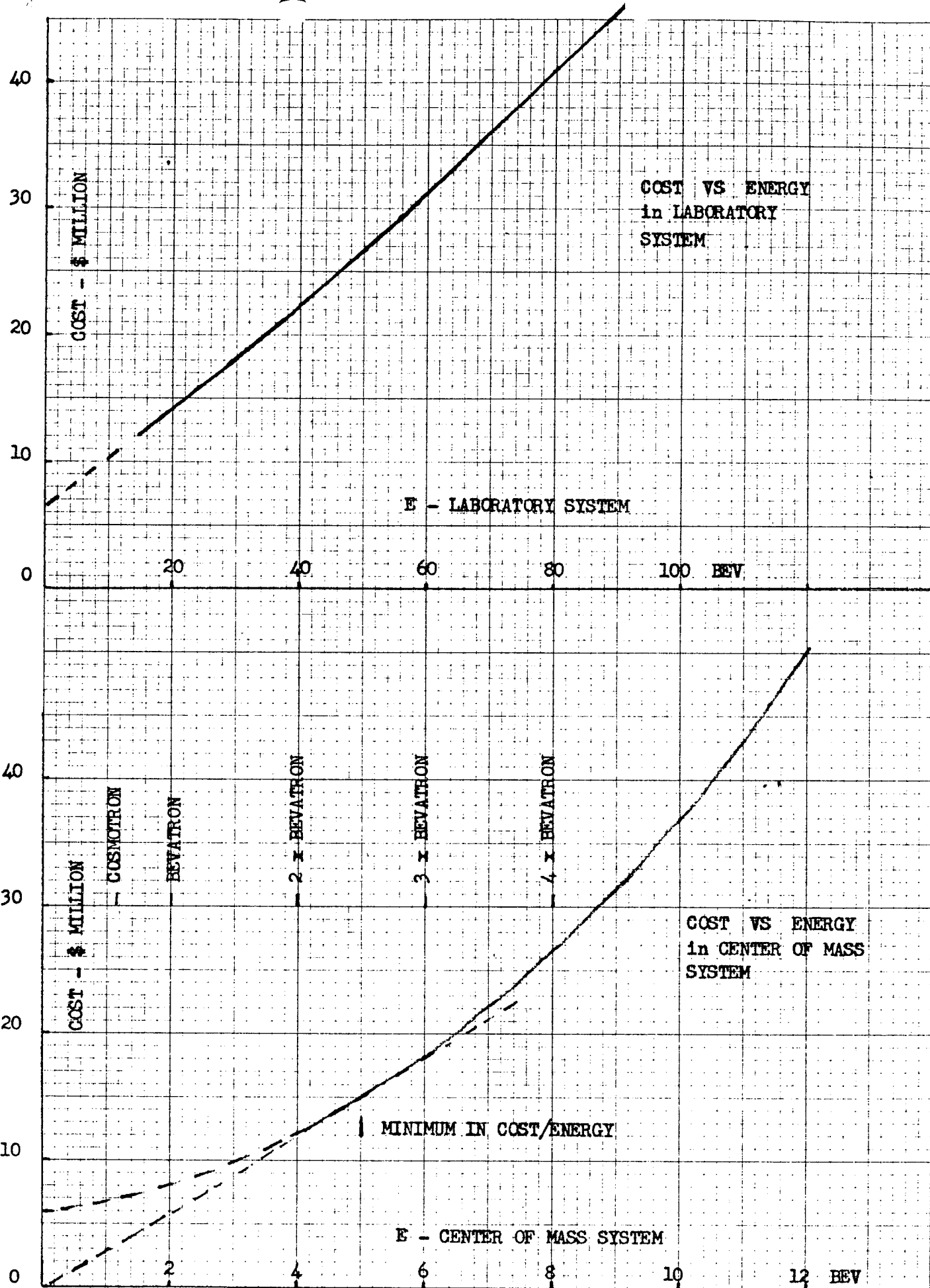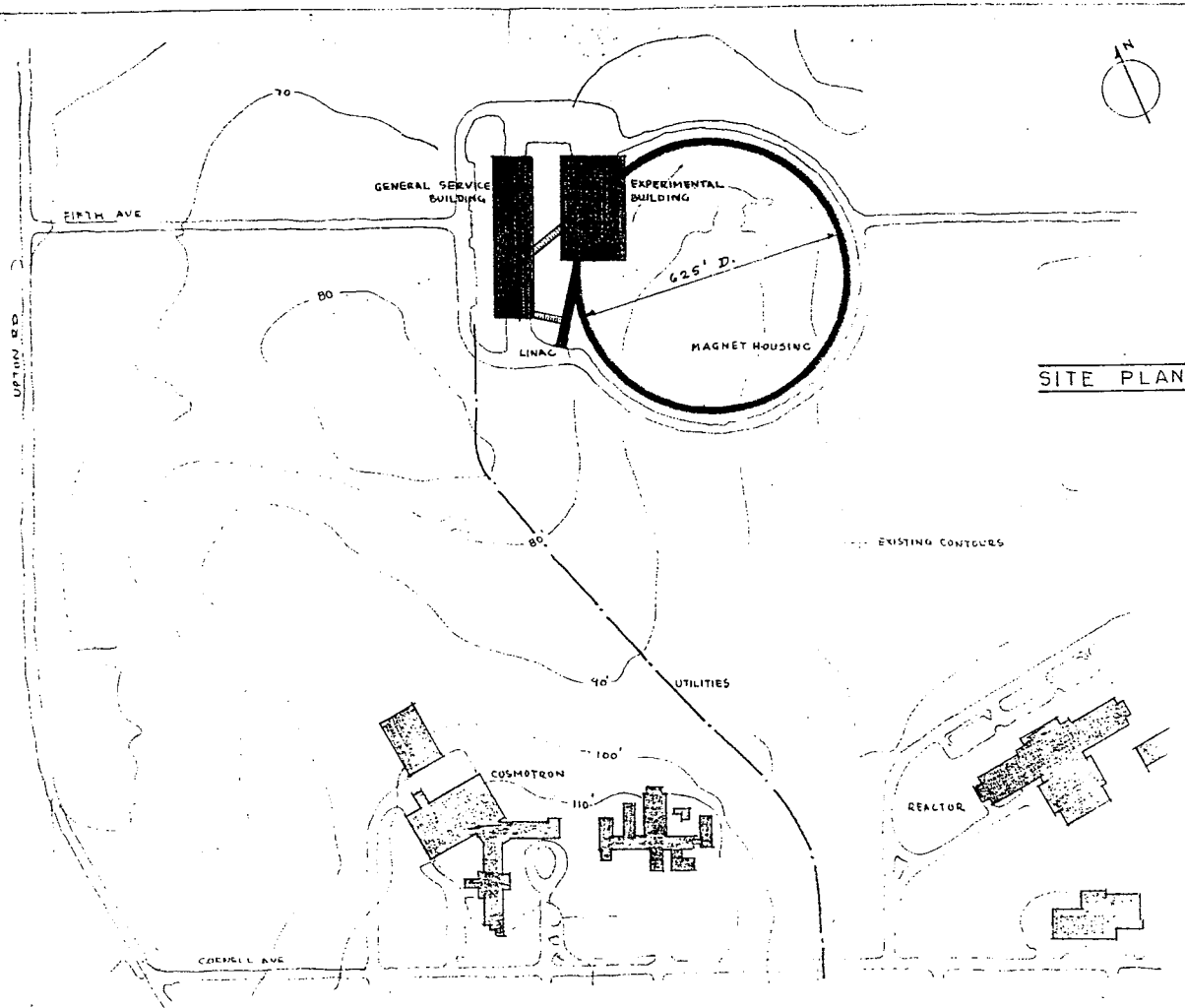   is for relative apertures one half those of the Cosmotron.

Fig. 2.

SITE PLAN

Labels within the figure:

- 70
- FIFTH AVE
- UPTON RD.
- GENERAL SERVICE BUILDING
- EXPERIMENTAL BUILDING
- 80
- 625' D.
- LINAC
- MAGNET HOUSING
- N
- EXISTING CONTOURS
- 80
- 90
- UTILITIES
- 100'
- COSMOTRON
- 110'
- REACTOR
- CORNELL AVE